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OPTIMIZATION OF PRETREATMENT CONDITIONS OF CARROTS TO MAXIMIZE JUICE RECOVERY BY RESPONSE SURFACE METHODOLOGY

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Abstract

Carrot juice was expressed in a hydraulic press using a wooden set up. Carrot samples pretreated at different designed combinations, using Central Composite Rotatable Design (CCRD), Response Surface Methodology (RSM), of pH, temperature and time were expressed and juice so obtained was characterized for various physico-chemical parameters which involved yield, TSS and water content, reducing sugars, total sugars and color (absorbance). The study indicated that carrots exposed to the different pretreatment conditions resulted in increased amount of yield than that of the control. The responses were optimized by numerical method and were found to be 78.23% yield, 0.93% color (abs), 3.41% reducing sugars, 5.53% total sugars, 6.69^{o}brix, and 90.50% water content. All the derived mathematical models for the various responses were found to be fit significantly to predict the data.

Keywords: Carrots, Physico-chemical, Optimization, Mathematical Models.

1. Introduction

India is the largest producer of fruits and second largest producer of vegetables in the world, next to China. Its share in the world's production is 11% and 7% in case of fruits and vegetables, respectively [1]. The carrots are consumed fresh or cooked, either alone or with other vegetables, in the preparation of soups, stews,

Nomenclatures

CCRD	Central Composite Rotatable Design
F_{cal}	F calculated
F_{tab}	F tabulated
LoF	Lacck of Fit
P	Probability
R^2	Coefficient of determination
RSM	Response Surface Methodology
X, Y	Constant
Y	Measured response
Greek Symbols	
βo	Intercept term
Bi,ij,ii	Constants

curries, and pies. Fresh grated roots are used in salads and tender roots are pickled [2]. In the carrot slicing, energy and peak force were mainly influenced by core diameter and central part of the carrot [3]. Attempts have been made to process this vegetable as canned, dehydrated, pickled, juice, preserve, puree, flakes, or as a frozen product. During processing, losses in soluble sugars, minerals, pectic substances and other solutes from carrots have been reported [4]. Ogunlesi and Lee [5] recommended a longer time lower temperature blanching for carrots, which improves the firmness of canned carrots at low cost. Kinetics of thermal softening of canned carrots during retorting has been reported [6]

Yield and quality of carrot juice extracted by pressing varied with the condition of any particular batch of carrots and pulp consistency after blanching and mashing [7]. Grinding from 6 to 2 mm particle size increased yield by 0.7%/mm for blanched and macerated carrots; it also increased juice color. Squeezing the blanched mash resulted in higher yields of juice and carotenoids than cold-squeezing. The effects of different blanching solutions and blanching times (1-5 min) on the quality of carrot juice was studied [8]. Chadha et al. [9] studied the effect of pectolytic and cellulolytic enzymes on the carrot juice recovery and concluded that incubation temperature and enzyme concentration were more pronounced than those of incubation time and enzyme ratio. Sharma et al. [10] optimized enzymatic process parameters for increased juice yield from carrot using response surface methodology.

Carrot is a nutritious vegetable and is widely known for various medicinal properties. To produce the juice, the industries/organized sectors adopt different pretreatment conditions to maximize the juice recovery. Big losses are resulted due to the lack of proper knowledge of the effect of pretreatment conditions on yield with respect to the optimum overall acceptability. Therefore, in order to have uniformity in terms of pretreatment conditions viz. time, temperature and acidic conditions to recover maximum yield of juice along with optimum overall acceptability, scientific efforts are required. Hence the present investigation was undertaken to optimize the pretreatment conditions of carrots especially of the red-orange commercial variety, most popular in India for the maximum juice recovery by using Central Composite Rotatable Design (CCRD), Response Surface Methodology (RSM).

2. Materials and Methods

The carrots were procured from the local market of Longowal, Punjab. The carrots were washed under running tap water, trimmed and peeled by using peeler to remove dirty skin, undesirable hair and end ones and again washed. The clean, sound carrots without any physical damage were selected for further processing.

2.1 Pretreatment

The washed, trimmed and peeled carrots were taken. The carrots were cut into 3-4 cm in diameter, 3 cm in thickness and weighed around 300g. The pH of water was maintained by using citric acid. The water was then heated to specific temperature and carrots were dipped in it for a specific period of time according to the designing conditions. The carrots were then removed from the hot water, allowed to cool and grated by using manual grating plate.

The juice was expressed at different pressure range (46.3 – 69.50 MPa) in a hydraulic press using a wooden setup (B. Sen Barry & Co., New Delhi) and the respective yield was recorded. It was observed that as the pressure was increased from 46.3 – 61.8 MPa, the yield of juice increased from 49.3 to 62.8%. For further increase in pressure to 69.5 MPa, the yield decreased to 60.2%. This decrease in the juice yield may be attributed due to the coming out of the carrot mash through the filter cloth, which required second filtration of the juice, which may have led to reduced juice yield. Therefore, a pressure of 61.8 MPa was considered optimum and was used in the study.

2.2 Experimental design

Response Surface Methodology (RSM) was adopted in experimental design and analysis [11]. A central composite rotatable design (CCRD) with augmented points in three variables, as given below, was used:

Coded variables					**Number of experiments**
X_1 (pH)	**X_2 (Temperature)**	**X_3 (Time)**	**Combinations**	**Replications**	
±1	±1	±1	8	1	8
±1.682	0	0	2	1	2
0	±1.682	0	2	1	2
0	0	±1.682	2	1	2
0	0	0	1	6	6

0 represents the centre point; ±1 for factorial points, and ±1.682 for augmented points

The level of parameters was carefully selected based on the literature available. The coding of the levels was done using the following equations:

$$X_1\ (\text{pH}) = (x_1-4.5)/1.3 \quad (1)$$

$$X_2\ (\text{temperature}, {}^0\text{C}) = (x_2-80)/11 \quad (2)$$

$$X_3\ (\text{time, s}) = (x_3-360)/140 \quad (3)$$

where X_1, X_2 and X_3 and x_1, x_2 and x_3 are coded and uncoded variables, respectively.

The range and the levels of the experimental variables used in the coded and uncoded form for the centre, factorial and augmented point of design are summarized below:

Experimental Variables	**Code**	**Coded level**				
		-1.682	**-1**	**0**	**1**	**1.682**
pH	X_1	2.31	3.2	4.5	5.8	6.69
Temperature, ^{o}C	X_2	61.50	69	80	91	98.50
Tim, s	X_3	124.55	220	360	500	595.45

2.2 Determination of juice yield

Juice yield was determined by the following expression:

$$\%\ Juice\ \ Yield = \frac{weight\ \ of\ \ carrots\ - weight\ \ of\ \ solids\ (cake)}{weight\ \ of\ \ carrots} \times 100 \quad (4)$$

2.4 Physicochemical analysis

Juice was subjected to various physicochemical parameters such as TSS, water, reducing sugars, total sugars and color (absorbance) by standard methods [12]. Reducing and total sugars were evaluated by Lane and Eynon Method. For the determination of color, 5ml of the carrot juice was diluted with 5ml of distilled water. The colorimeter was set to zero by using distilled water. Then the sample was filled in the cuvette and the absorbance was measured at 472 nm using colorimeter. The total soluble solid (^{0}brix) of carrot juice samples was measured by using hand refractometer.

2.5 Statistical analysis

Design Expert software 'DE – 6' was used for regression and graphical analysis of the data (Stat-Ease, 2000). The optimum values of the selected variables were obtained by solving the regression equation and by analyzing the response surface contour plots.

3. Results and Discussion

The yield, total soluble solids (TSS) and water content, reducing and total sugars and color under different pretreatment conditions were determined and a second order polynomial of the following form was fitted to the data of all the responses as the results are reported in Table 1:

$$Y = \beta o + \sum_{i=1}^{3} \beta iXi + \sum_{i=1\ (j<i)}^{3} \sum_{j=1}^{3} \beta ijXiXj + \sum_{i=1}^{3} \beta iiXi^{2} \qquad (5)$$

where Y is the measured response, βo, intercept term, β_i, βij , and βii are the constant coefficients. The variable X_iX_j represents the first- order interactions between X_i and X_j for (j<i).

Table 1. Regression coefficients of the second order polynomial and their significance.

Coefficients	Juice Yield	Color	Reducing sugars	Total sugars	Water content	TSS
β_o	76.94	0.83	3.30	5.47	91.09	6.28
β_1	-2.66	-0.09	-0.13	-0.055	0.55	-0.28
β_2	0.78$^!$	-0.04	-0.03***	-0.012$^!$	0.05$^!$	-0.09
β_3	1.85	0.03	-0.12	-0.20	0.53	-0.33
β_{11}	-0.78$^!$	-0.01	-0.04*	-4.8E-3$^!$	-0.09$^!$	0.08$^!$
β_{22}	-0.86***	-0.03	-2.8E-3$^!$	-0.061	0.36	-0.10
β_{33}	-1.25**	-0.02	-0.09	-0.091	0.37	-0.15
β_{12}	0.04$^!$	0.02	-7.5E-3$^!$	0.015$^!$	0.10$^!$	-0.01$^!$
β_{13}	0.46$^!$	5.0E-3$^!$	7.5E-3$^!$	-0.078	0.02$^!$	-0.11
β_{23}	-0.11$^!$	0.00$^!$	-7.5E-3$^!$	7.5E-3$^!$	0.11$^!$	-0.01$^!$
R^2, %	88.19	9.9.17	95.73	98.03	93.60	98.33
F	7.47	119.90	22.43	49.88	14.62	58.85
Adeq. precision	8.51	35.01	14.2	21.62	13.98	28.40
Adj. R^2, %	76.39	98.35	91.46	96.07	87.20	96.66
Pred R^2, %	37.99	93.48	66.35	83.32	66.06	89.25
LoF	No	No	No	No	No	No

Significant at 10% (***), 5% (**), not significant (!) and all other values are significant at 1% level; Table $F_{(9,9)\ tab} = 3.21$

3.1 Juice yield

Carrot juice yield varied from 67 to 79% for the samples treated under different conditions as against 62.8% for control sample. The coefficient of determination, R^2, was 0.8819 for the regressed model predicting the %juice yield, which shows 88.19% variability in the data. Adeq Precision of 8.51 indicated about the adequacy of the model (Table 1) . The F-value for the model was 7.47 which is greater than the tabulated F value 3.21 indicating the adequecy of the model to predict % juice yield at different pretreatment conditions (P<0.05). The lack of fit was not found significant

($F_{cal} < F_{tab}$). Time and pH were found to be the significant model terms (P<0.05). The juice yield increased with decrease in pH and increase in time.

3.2 TSS and water content

The average total soluble solids (TSS) and the water content of the juice expressed from untreated carrots were 6.9°brix and 89.66% respectively. In case of juice obtained after pretreatment of carrots, TSS varied from 5.3 to 6.7°brix and water content varied from 89.96 to 92.96%. The decrease in TSS with increase in time might be due to leaching of some of the soluble solids in water. The decrease in the soluble solids in case of raw juice and carrots boiled in water, has earlier been reported [8]. The maximum value of TSS, 6.7, was obtained when the pH, time and temperature was 2.31, 80°C and 360s and the minimum value, 5.3, was obtained at 4.5, 80°C and 595.45s. The coefficient of determination, R^2, was 0.9833 for the regressed model predicting the TSS and 0.9360 predicting the water content. Data also indicated the insignificance of the lack of fit ($F_{cal} < F_{tab}$) confirming the significance of the model (Table 1). The water content varied with both pH and time but temperature did not have significant effect on water content.

3.3 Reducing and total sugars

The reducing sugars and total sugars of the control sample were 3.39% and 5.62% respectively. After the pre-treatment, the reducing sugar came out to be in the range of 2.84 - 3.42% whereas total sugars were 4.89 - 5.9%. A significant reduction has been reported in soluble sugars, fructose, glucose and sucrose in the processed samples (blanching) [13]. The coefficient of determination, R^2, predicting the %reducing sugars and total sugars, showed 95.73% and 98.03% respectively variability in the data (Table 1). The F-value for the reducing sugars and total sugars models were 22.43 and 49.88 respectively and lack of fit was not significant ($F_{cal} < F_{tab}$), thus confirming the significance of the models in predicting the reducing and total sugars.

3.4 Colour

Colour value of the carrot juice after pretreatment varied from 0.64 to 0.96. The color value, 0.97 of the control sample was greater than the color values of the pretreated samples. The decrease in the color values may be due to exposure of the samples at different pH and temperatures for a specified period of time thereby causing degradation to the heat sensitive color constituents. The maximum value of color was obtained when the pH, time and temperature was 2.31, 80°C and 360s and the minimum value of color was obtained at 6.69, 80°C and 360s. Adequate precision of 35.01, F value, R^2 and LoF indicated that the model is highly adequate. In the model, pH, temperature and time were found to be the significant model terms (P<0.01).

3.5 Optimization of parameters to maximize juice yield

Design expert software was used to optimize the juice yield with respect to the overall acceptability. The software uses second order model to optimize the responses. The uncoded form of input variables i.e. pH, temperature and time was optimally found to be 3.2, 91ºC and 500s respectively.. In practice, however, it is difficult to maintain the recommended conditions during processing and some deviation is expected. Therefore, optimum conditions were varied as pH 3.2 ± 0.14, temperature 91 ± 1^{o}C, and time 500 ± 15s which were predicted by using second order polynomial. It was observed that the optimum values of juice yield was found to be 78.23% with respect to other optimum responses as summarized below:

Process variables	**Optimum value**		**Response**	**Optimum value**
	Uncoded	**Coded**		
pH	3.2	-1.00	Yield (%)	78.23
Temperature (^{0}C)	91	1.00	Color (abs)	0.93
Time (s)	500	1.00	Reducing sugars (%)	3.41
			Total sugars (%)	5.53
			TSS (^{o}brix)	6.69
			Water content (%)	90.50
			Desirability (%)	0.838

In all the cases, the desirability is greater than 80%, thus proper pretreatments before the expression of the juice may result increase in juice yield as high as 11.5%.

4. Conclusions

Carrots exposed to the different pretreatment conditions resulted in increased juice yield. The yield was found to be maximum, 78.23% at pH, temperature and time of 3.2, 91^{o}C and 500s respectively. The optimized responses were found to be 78.23% yield, 0.93 color (abs), 3.41% reducing sugars, 5.53% total sugars, 6.69^{o}brix, and 90.50% water content.The desirability for all the responses was found to be 83.8%. All the derived mathematical models for the various responses were found to be significantly fit to predict the data.

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